ADDITIONAL EVIDENCE FOR QUASI-BIENNIAL VARIATIONS IN TROPOSPHERIC PARAMETERS

J. K. ANGELL and J. KORSHOVER

Air Resources Laboratories, ESSA, Silver Spring, Md.

ABSTRACT

During the years 1899–1967, in temperate latitudes of the Northern Hemisphere, there has been a significant quasi-periodic fluctuation (hereafter denoted as periodicity) of about 16 yr. in the even minus odd (even−odd) year difference in sea level zonal geostrophic wind for the months January through May. No such periodicity is evident for the months July through November. For the winter and spring months there is also a significant correlation between even−odd year difference in sea level zonal wind around the hemisphere (at the appropriate latitude) and the even−odd year difference in surface temperature in western Europe. On the basis of this periodicity and correlation, long-range prediction of surface temperatures in western Europe during winter and spring should exhibit modest skill. Sparse pressure data suggest that similar periodicities in sea level zonal wind are present in the Southern Hemisphere and that, at least at lat. 30° during the period January–May, the periodicities in the two hemispheres are basically in phase.

In the Northern Hemisphere winter and spring, at 500 mb., evidence is presented for periodicities of about 16 yr. in the even−odd year differences of zonal wind, temperature, and meridional momentum and heat flux. These periodicities, as well as the one for the sea level zonal wind, tend to be in phase. There is a strong out-of-phase relation between the even−odd year difference in sea level zonal wind in midlatitudes and the total ozone at Arosa, and a strong in-phase relation between this wind and the even−odd year difference in temperature in the tropical stratosphere 1 yr. earlier.

1. INTRODUCTION

Angell and Korshover [1] recently showed that, during the past decade in extratropical latitudes, spring temperatures in the lower stratosphere tended to be relatively high during the even years and relatively low during the odd years. This tendency was particularly pronounced in the Southern Hemisphere, where there was the suggestion of a poleward trend of the even-year temperature excess. The purpose of this paper is to extend this stratospheric evidence for a yearly alternation into the troposphere, using a similar analysis procedure.

2. PROCEDURE

The "spring" months used herein consist of January through May for the Northern Hemisphere and July through November for the Southern Hemisphere. This differs from [1] where January through March, February through April, and March through May were used to represent "spring" months in the tropical, temperate, and polar latitudes, respectively, of the Northern Hemisphere. The earlier differentiation according to latitude now seems arbitrary, and accordingly, in this paper, the averages for the 5-mo. periods January–May and July–November are used for all latitudes. Note that, through the use of these months, the year has to some extent been partitioned into winter and summer seasons. This, in fact, may be advantageous because there is evidence that the year-to-year differences in certain meteorological parameters (momemtum flux, for example) occur mainly in winter (Wallace [2] and Miller et al. [3]).

As discussed in [1], the analysis procedure involves the formation of a new series from the sequence of first differences of the original series of meteorological values (zonal wind, temperature, etc.), with alternate signs of the difference reversed so as to yield a measure of the excess of even-year values over odd-year values, or vice versa. These differences are then smoothed through use of a 3-yr. running mean. It is recognized that, thereby, an anomolous or erroneous value for any particular year will tend to produce a transient 6–8-yr. periodicity. Consequently, fluctuations of period 10 yr. or less should be interpreted with care. Throughout this paper, for simplicity, the term "periodicity" is used in place of the more appropriate expression "quasi-periodic fluctuation," but it is emphasized that in no case are we dealing with a strictly periodic phenomenon.

3. YEARLY ALTERNATION IN SEA LEVEL ZONAL GEOSTROPHIC WIND

With the exception of the war years, 1939–1945, sea level pressures averaged zonally around the Northern Hemisphere are available from 1899 to the present. Based on the difference in these average pressures for every 10° of lat. from 20°N. to 70°N., even−odd year

TABLE 1.—*Stations used to estimate even—odd year differences in sea level zonal geostrophic wind between 1939–1945. The right hand column gives the latitudes to which the sea level pressure data are assumed to apply*

Pacific Section	American Section	European-African	Latitude
Barrow	Arctic Bay	Bodo	70°N.
Anchorage	Chesterfield	Bergen	60°N.
Dutch Harbor	White River	Frankfurt	50°N.
Akita	Washington	Palma	40°N.
Kagoshima	Jacksonville	El Golea	30°N.
Honolulu	Jamaica	Khartoum	20°N.

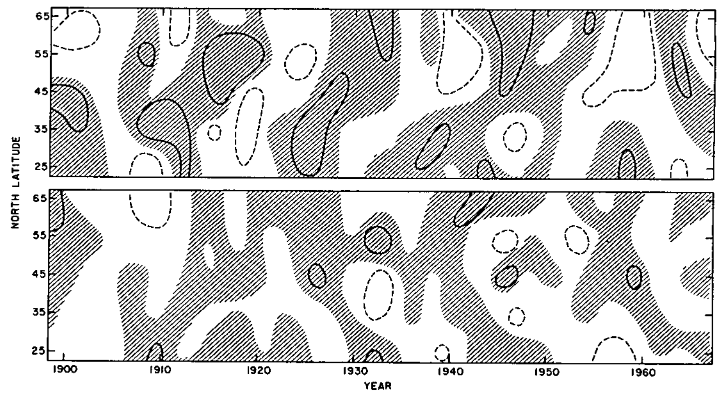

FIGURE 1.—Variation with year and north latitude of even—odd year difference in sea level zonal geostrophic wind for the months January–May (top) and July–November (bottom). The hatching indicates stronger west winds in the even years; the isopleths delineate areas where the even—odd year zonal wind difference exceeds 1 m. sec.$^{-1}$

differences in sea level zonal geostrophic wind were evaluated. For the war years, sea level pressures for stations on quasi-meridional sections through the Pacific, America, and Europe-Africa (table 1) were averaged, and the associated zonal geostrophic winds determined. Of course, these latter values may not represent a true hemispheric average, and should be accepted with caution.

Figure 1 shows the even—odd year difference in sea level zonal geostrophic wind as a function of year and north latitude. The hatching signifies that stronger west winds occurred during the even years for the months January–May (top) and July–November (bottom), while the blank areas signify that stronger west winds occurred during the odd years for these months. The isopleths delineate average year-to-year zonal wind differences exceeding 1 m. sec.$^{-1}$ As would be expected from considerations of the frictional torque between earth and atmosphere, there tends to be compensation between high and low latitudes, i.e., if the west wind is relatively strong during an even year in high latitudes, it is relatively weak during the same year in low latitudes. Between 30° and 60°N. the correlation in even—odd year zonal wind difference is −0.59 during January–May (winter–spring) and −0.31 during July–November (summer–fall).

Based on the data summarized in figure 1, there is little correlation between the even—odd year zonal wind differences in winter–spring and summer–fall, with nonsignificant correlations of −0.25, 0.28, 0.14, −0.18, and 0.00 at latitudes 25°, 35°, 45°, 55°, and 65°N. respectively. Accordingly, the even—odd year differences in zonal wind appear not to persist throughout the year. Two obvious differences between winter–spring and summer–fall are the magnitude of the year-to-year variability (nearly twice as great in the first instance) and the degree of order in the variability. Particularly between 1910 and 1940, there is a pronounced periodicity, and apparent poleward trend, in the even—odd year zonal wind difference during winter–spring. In line with the latter observation, based on the whole 68 yr. of record, a (maximum) correlation of 0.40 results if the even—odd year differences at 30°N. are advanced 6 yr. with respect to the differences at 60°N.

Figure 2 presents correlograms of the even—odd year sea level zonal geostrophic wind difference at various latitudes for winter–spring and summer–fall. In midlatitudes, where the data are most reliable, systematic autocorrelations of 0.5–0.6 are obtained at lags of about 16 yr. in winter–spring. An optimistic estimate of the significance of these correlations is obtained by applying Fisher's Z test to the individual autocorrelations as if they were conventional correlations between two separate parameters. It is thereby found that an autocorrelation of 0.5 is significant at the 4 standard deviation level (one chance in 1,000 that such a correlation would be obtained by sampling normal distributions). A pessimistic estimate is obtained by determining the chance of obtaining a correlation of 0.5 or greater when 12 different evaluations are made (12 different lags utilized). Mitchell et al. ([4], p. 41)

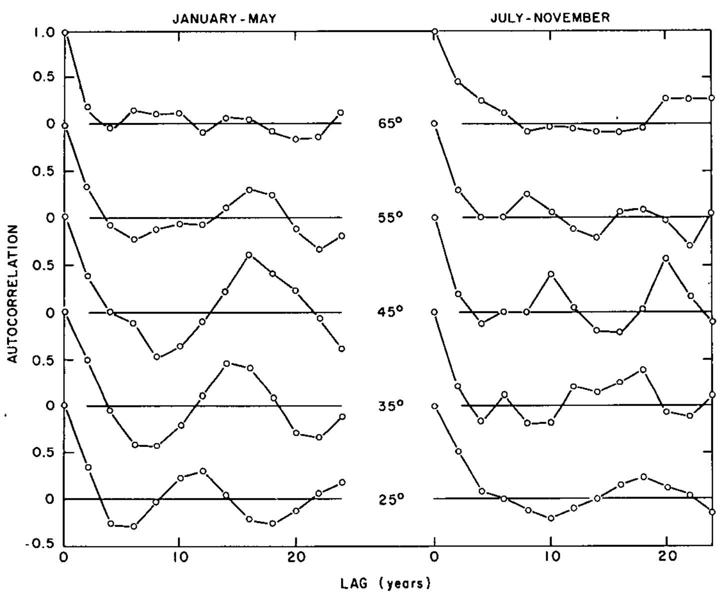

FIGURE 2.—Based on the period 1899–1967, correlograms of even—odd year difference in sea level zonal geostrophic wind at given north latitudes for the months January–May (left) and July–November (right).

point out that, in effect, through the evaluation of 12 different lags one reduces the significance of the Fisher test by slightly more than an order of magnitude. Thus, even from the most conservative point of view, there is only about one chance in 100 that an autocorrelation of 0.5 would be obtained by chance from 68 observations, and consequently the autocorrelation values at 35° and 45°N. in winter-spring must be judged quite significant. Accordingly, there is good evidence for about a 16-yr. periodicity in even—odd year zonal wind difference at this time of year in these latitudes.

During July–November, there is no systematic variation in autocorrelation at any latitude other than 25°N., where there is some evidence for an 18-yr. periodicity. A correlation exceeding 0.50 is obtained in one case. The occurrence of such a value in one trial out of 60 is to be expected based on the above (pessimistic) significance test. Certainly, however, one would not claim the existence of any significant periodicity on the basis of the July–November autocorrelations.

The correlogram peak at a period of 11 yr. at 25°N. in winter–spring is puzzling. The pessimistic significance test mentioned above indicates almost a 50-percent chance of obtaining an autocorrelation value of 0.25. Nevertheless, the regularity of the trace is impressive. This 11-yr. periodicity may well result from a mix of the longer periodicity at midlatitudes and pressure uncertainties in the subtropics, but it is difficult for any author to bypass an 11-yr. periodicity without at least a glance at solar activity. While there is no reason to expect a relation between sunspot number and even—odd year differences in meteorological parameters, after 1900, all Zurich sunspot maxima over 100 occurred in odd years (1917, 1937, 1947, 1957). Consequently, there is a negative correlation between sunspot number and even—odd year sunspot number, and a correlation of 0.41 between even—odd year difference in sea level zonal geostrophic wind at 25°N. during January–May and even—odd year difference in sunspot number. This correlation is significant at the 5-percent level, but not at the 1-percent level, according to Fisher's test. It is unlikely there is anything of significance here, but it is a curiosity to keep in mind.

In regions where the surface temperature is closely attuned to the magnitude and direction of the zonal wind (for example, western Europe), one might expect a good correlation between even—odd year difference in sea level zonal wind and surface temperature. This would, for example explain the 17-yr. periodicity in even—odd year surface temperature difference for European stations reported in [1]. Using the three groups of three stations each worked up for [1] (Bergen, Oslo, Uppsala; Basel, Geneva, Vienna; New Haven, Montreal, Toronto), as well as two new groups of three stations each (Edmonton, Juneau, Nome; Kagoshima, Miyako, Nemuro), the correlations in table 2 were obtained. The correlations are generally in the sense expected, with relatively strong west winds bringing relatively warm air into Scandinavia and Central Europe and relatively cool air into southeastern Canada, Alaska, and Japan, although the latter correlations are very small. The magnitude of the correlation is surprisingly large in Scandinavia (0.74) and Central Europe (0.59) when one considers that regional temperatures are being compared with hemisphere-wide pressure gradients. At least in these regions, there should be some modest, long-range predictive skill in surface temperature forecasts based on extrapolation of the periodicities delineated by figure 1. It will be interesting to see, for example, whether the winter–spring of 1968 is relatively cool in Scandinavia (say 1°C. below normal), as would be implied by figure 1.

TABLE 2.—*Correlation between even—odd year difference in sea level zonal geostrophic wind (at the appropriate latitude around the Northern Hemisphere) and surface temperature (based on three-station groups) for the months January–May for the period 1899–1967*

Stations	Correlation
Bergen, Oslo, Uppsala	0.74
Basel, Geneva, Vienna	.59
New Haven, Montreal, Toronto	−.04
Edmonton, Juneau, Nome	−.26
Kagoshima, Miyako, Nemuro	−.02

It is desirable to expand the above analysis into the Southern Hemisphere. However, this is difficult because of the sparseness of pressure data in that hemisphere, both in space and time. From 1910 until the present, sea level pressure data are available for Hobart (43°S., 148°E.) and Cloncurry (21°S., 141°E.) and for Buenos Aires (35°S., 58°W.) and Rio de Janeiro (23°S., 43°W.). The even—odd year difference in zonal geostrophic wind determined for each meridian was averaged to yield an estimate of this difference around the hemisphere at a lat. of 30°S. The correlogram based on these data (fig. 3) suggests the presence of about an 18-yr. periodicity in sea level zonal geostrophic wind at 30°S. for both January–May and July–November, with autocorrelations as high as 0.30. There may be some significance in the fact that, in the troposphere, the large yearly alternations during the Northern Hemisphere winter–spring appear to be associated with similarly large alternations during the Southern Hemisphere summer–fall, whereas the reverse is not true.

Pressure differences between South America and Antarctica, and between New Zealand and Antarctica, permit evaluation of the even—odd year difference in zonal geostrophic wind at about 60°S., but only for the last 10 yr. Consequently, it is impossible to obtain an accurate estimate of the even—odd year periodicity in the "screaming sixties." Table 3 shows the correlation between the even—odd year difference in sea level zonal wind at lat. 30° and 60° in the two hemispheres. In view of the abovementioned periodicities, it is not surprising that there is a fair correlation during January–May but little correla-

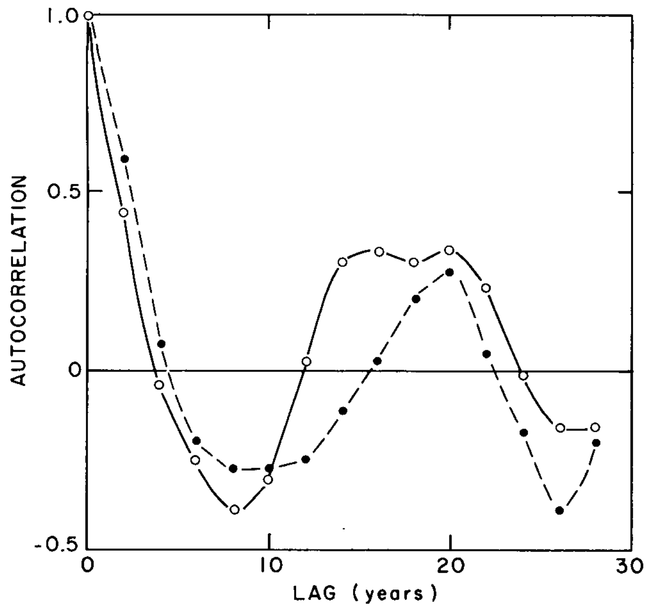

FIGURE 3.—Based on the period 1910–1967, correlograms of even—odd year differences in sea level zonal geostrophic wind at 30°S. for the months January-May (solid line) and July-November (dashed line).

tion during July–November. The correlation of 0.32 at 30° during January–May is significant at the 5-percent level according to Fisher's test. Thus, these preliminary results suggest some symmetry about the Equator during the Northern Hemisphere winter–spring.

4. YEARLY ALTERNATION IN 500-MB. ZONAL WIND

Needless to say, the 500-mb. data record is quite short compared to that at sea level. Figure 4 shows the even—odd year difference in zonal geostrophic wind at 500 mb. in the Northern Hemisphere for the 10-yr. period 1955–1965. During January–May there is good agreement with figure 1, with the exception of high latitudes near the end of the record. During July–November the agreement is not so obvious.

Of particular interest is the fact that the meridional flux of geostrophic angular momentum was estimated at 500 mb. for the same 10-yr. period. Figure 5 presents the even—odd year difference in this flux at lat. 20°, 45°, and 70°N. At the midlatitude, during winter–spring, there is a pronounced periodic variation, with the northward momentum flux a maximum in odd years before 1962 and in even years after 1962. Since the biennial variation in momentum flux at lat. 20° and 70°N. is small, this would lead to relatively strong west winds south of 45°N. in the even years prior to 1962, and north of 45°N. in the even years after 1962, in agreement with figure 4. Thus, in winter–spring, there is internal consistency between the yearly alternations in momentum and momentum flux. During summer–fall, however, there is little systematic variation in either parameter.

TABLE 3.—*Correlation between even—odd year difference in sea level zonal geostrophic wind in the two hemispheres*

Latitude	Period of Record	Correlation	
		Jan.-May	July-Nov.
30°	1910-1967	0.32	0.18
60°	1956-1967	.50	−.57

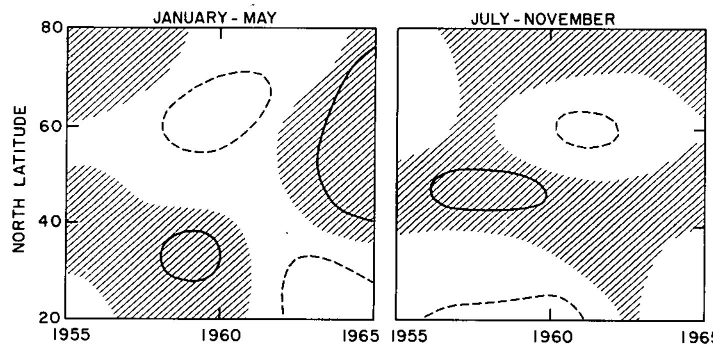

FIGURE 4.—Variation with year and north latitude of even—odd year difference in 500-mb. zonal geostrophic wind for the months January–May (left) and July–November (right). Otherwise, see legend for figure 1.

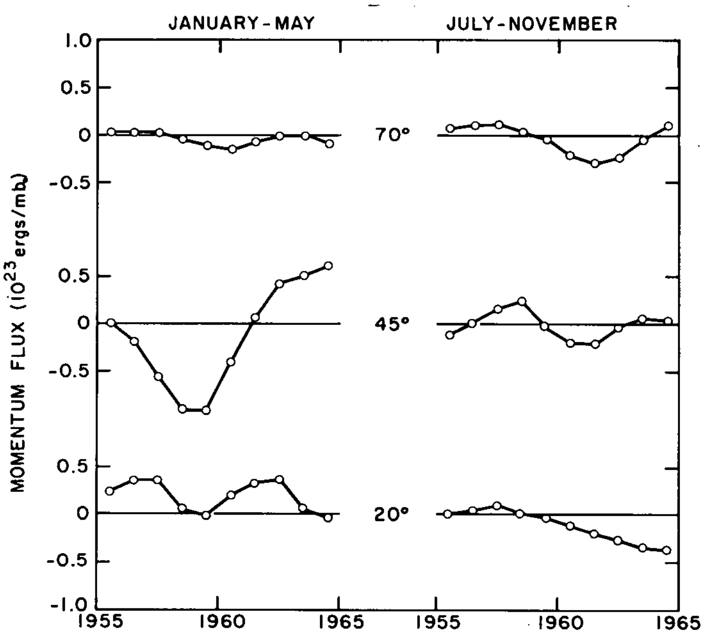

FIGURE 5.—Even—odd year difference in meridional, geostrophic angular momentum flux at 500 mb. at different north latitudes for the months January–May (left) and July–November (right). Positive values signify a greater poleward flux in the even years.

Finally, for completeness, the even—odd year difference in 500-mb. zonal wind was determined at individual stations along three quasi-meridional sections (Pacific, North America, Europe-Africa) and an average difference obtained, as is done for temperature subsequently. The stations with asterisks in table 4 show the wind data available to us. The resulting pattern (fig. 6) is quite

TABLE 4.—*Stations used to estimate even—odd year difference in 500-mb. temperature, and zonal wind (asterisks). The right hand column gives the latitudes to which the data are assumed to apply.*

Pacific Section	American Section	European-African Section	Latitude
	Eureka*	Nord	80°N.
Barrow*	Mould Bay*	Mayen	70°N.
Anchorage*	Coral*	Lerwick*	60°N.
Wakkanai*	Moosonee*	Valentia*	50°N.
Akita*	Washington*	Lisbon*	40°N.
Shiomanisaki*	Charleston*	Madeira*	30°N.
Clark Field*	San Juan*	Dakar	20°N.
Koror*	Balboa*	Lagos	10°N.
Canton*	Bogota*	Nairobi	0°
Darwin	Lima	Ascension I.	10°S.
Townsville	Antofagasta	Broken Hill	20°S.
Brisbane	Quintero	Pretoria	30°S.
Auckland	Puerto Montt	Malan	40°S.
Invercargill	Stanley	Marion I.	50°S.
McQuarie	Argentine I.		60°S.
Mawson	Argentine I.		70°S.
McMurdo	Byrd		80°S.
Amundsen	Amundsen		90°S.

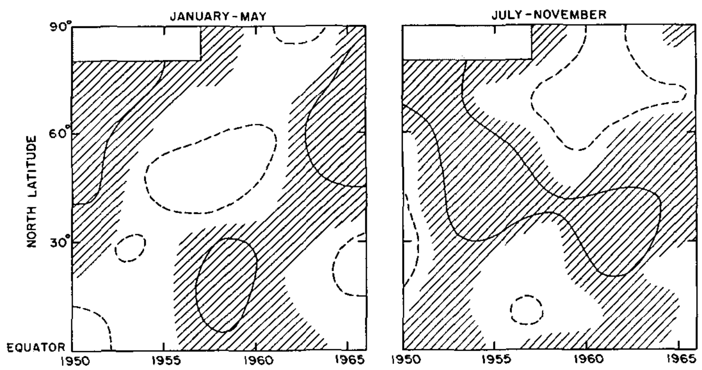

FIGURE 6.—Variation with year and north latitude of even—odd year difference in 500-mb. zonal wind for the months January–May (left) and July–November (right). Differences based on values along quasi-meridional sections through the Pacific, America, and Europe-Africa. In this, and subsequent diagrams, the stippling indicates no data. Otherwise, see legend for figure 1.

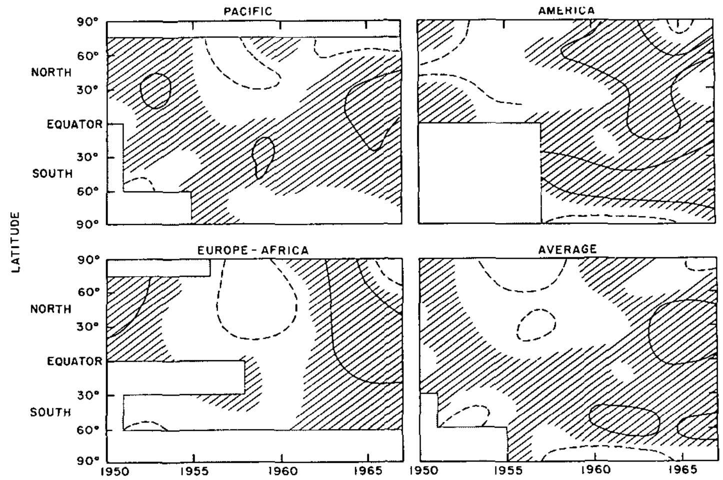

FIGURE 7.—Variation with year and latitude of even—odd year difference in 500-mb. temperature for the months January–May. Differences based on values along quasi-meridional sections through the Pacific, America, and Europe-Africa. The hatching indicates higher temperatures in the even years; the isopleths delineate areas where the even—odd year temperature difference exceeds 0.5°C.

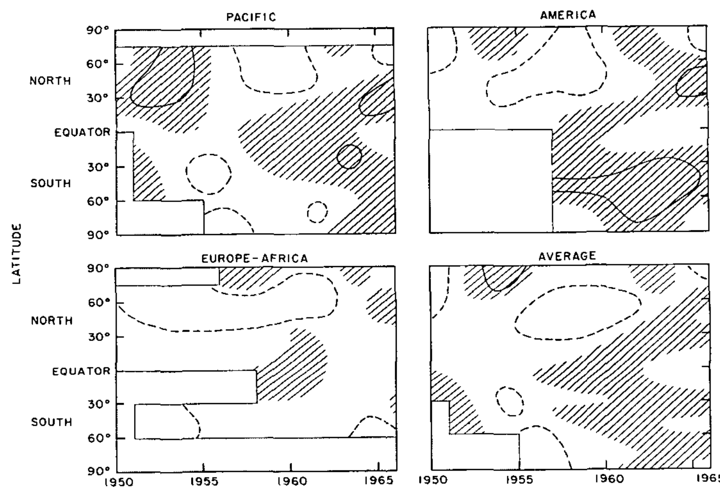

FIGURE 8.—Same as figure 7 for the months July–November.

systematic in January–May and is in general agreement with the patterns in figures 1 and 4, except that a poleward progression of the even—odd year differences is indicated. Obviously, it will be very difficult to decide whether there is really a poleward progression of the difference phenomenon, or simply a change in phase at about lat. 45°. At this time, the latter seems the more likely.

5. YEARLY ALTERNATION IN 500-MB. TEMPERATURE

The even—odd year difference in surface temperature for specific regions was discussed briefly in [1], and in this paper we have shown that in some cases these differences are closely associated with the differences in zonal geostrophic wind at sea level. Consequently, we will not consider surface temperatures further, but instead turn to an analysis of 500-mb. temperatures. For the analysis of the yearly alternation in these temperatures we have been forced to rely upon an average of the three, quasi-meridional sections through the Pacific, America, and Europe-Africa. Table 4 shows the stations used.

In view of the above-mentioned association between even—odd year difference in surface temperature and zonal wind, one might expect considerable variation in the 500-mb. even—odd year temperature difference at different longitudes. However, the differences among the sections tend to be rather minor, as shown by figures 7 and 8. Figure 7 indicates that, during January–May in most regions of the Northern Hemisphere, even-year 500-mb. temperatures were relatively low between 1953 and 1961 and relatively high between 1950–53 and 1961–67. There is some tendency, however, for the fluctuation to occur earlier in the American sector. The Southern

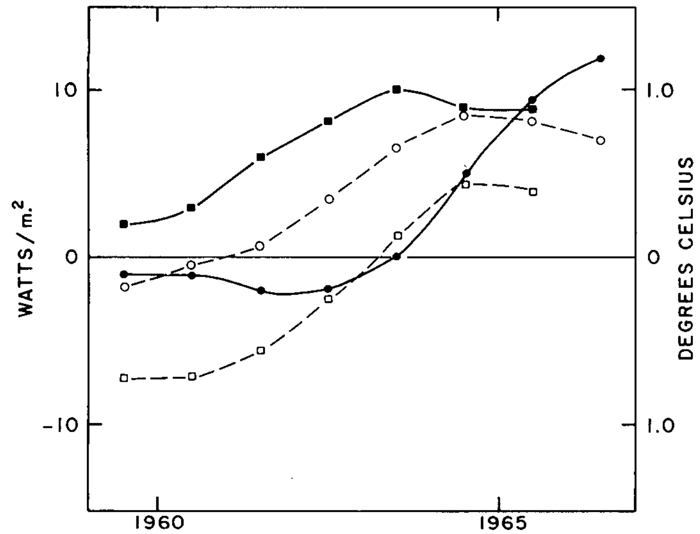

FIGURE 9.—Even—odd year difference in meridional heat flux (solid lines) for the months January–May (dots) and July–November (squares). The flux refers to a latitude of about 45°N. and in effect, extends through the layer 850–200 mb. The dashed lines represent corresponding even—odd year 500-mb. temperature differences at 45°N. as copied from the lower right hand diagrams of figures 7 and 8.

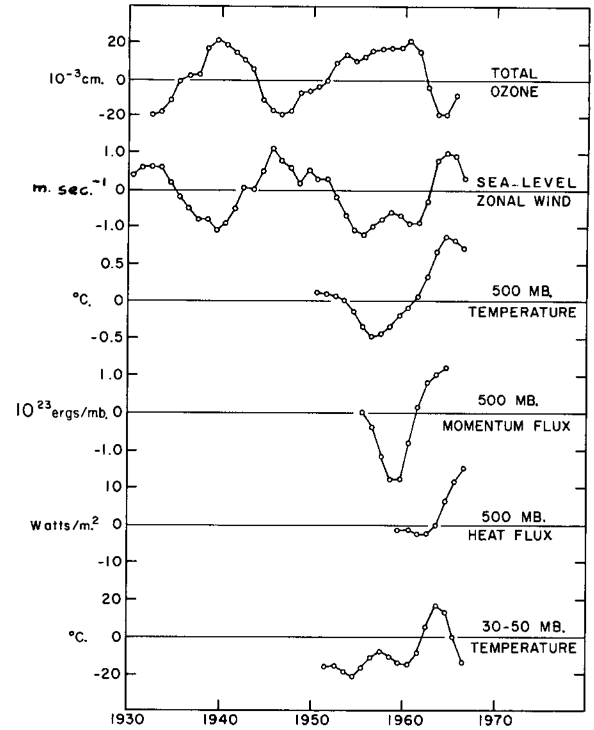

FIGURE 10.—Even—odd year difference in various parameters for the months January–May. All data refer to lat. 45°N. except for the bottom trace which refers to the average of data at 30 and 50 mb. in tropical latitudes (9°N.). The heat flux actually applies to the layer 850–200 mb.

Hemisphere exhibits quite a different variation, with evidence for relatively high even-year temperatures in midlatitudes, and relatively high odd-year temperatures in polar latitudes, through most of the period.

Whereas in the case of the zonal wind there was little apparent system to the even—odd year differences during summer–fall, in the case of temperature (fig. 8) there is a surprisingly systematic behavior. Furthermore, there is evidence of symmetry with respect to the Equator. In general, relatively warm July–November periods at 500 mb. in even years are associated with relatively strong sea level west winds in January–May periods of even years, with a correlation between the two of 0.88 between 1950 and 1967 at 45°N. This raises the interesting possibility of a few months lag between 500-mb. temperature and strength of the zonal wind at sea level.

For comparison with these temperature patterns, it would be desirable to have available meridional heat flux data as a function of latitude. Haines and Winston [5] present such data (based on 850–500-mb. thickness patterns) for a 4-yr. period, but this is too short a time for use here. However, Krueger et al. [6] show that there is a good correlation between meridional heat flux and the conversion between zonal and eddy available potential energy, and the latter is available (based on the height interval 850 and 200 mb.) from 1959 to the present. Unfortunately, there is no differentiation with respect to latitude, and we must assume that the data apply to a mean lat. of 45°N. Figure 9 shows the even—odd year difference in this "flux" for winter–spring and summer–fall and, for comparison, the average even—odd year difference in 500-mb. temperature at lat. 45°N. as obtained from figures 7 and 8. The temperature and heat-flux traces have the same trend, implying, not unreasonably, that at midlatitudes a relatively large meridional heat flux during a given year is associated with a relatively high 500-mb. temperature during that year. There are, however, discrepancies. For example, early in the period of record, the summer–fall heat flux is greater in the odd years, yet the temperature is greater during the even years. In general, the even—odd year difference in winter–spring heat flux is in phase with the momentum flux (fig. 5), as would be anticipated.

6. SUMMARY

Figure 10 summarizes the even—odd year differences for the months January through May. The even—odd year difference in total ozone at Arosa (47°N.) was treated in [1], and it is plotted at the top of figure 10. The extent to which this single station is representative of hemispheric condition is, of course, unknown, though it was shown in [1] that the even—odd year difference traces at Shanghai and Arosa tended to be similar during the 1930's. For comparison with the ozone trace, we have plotted a segment of the even—odd year difference in sea level zonal geostrophic wind at 45°N. for the same winter–spring period. The out-of-phase relationship is striking, with a correlation between the two of −0.88 for the interval 1932–1966. Such a correlation is significant at the 8 standard deviation level according to Fisher's test so that there is good evidence that, during January–May, a relatively weak sea level west wind is associated with a relatively large total ozone amount. This may reflect an enhanced meridional mixing in the stratosphere at a time when the westerlies are relatively weak.

The even—odd year difference in 500-mb. temperature at 45°N. is also out of phase with the ozone trace, as would be expected due to the correlation between total ozone amount and stratospheric temperature, and the temperature compensation that tends to occur between stratosphere and troposphere (cool troposphere associated with warm stratosphere, and vice versa). The even—odd year difference in 500-mb. momentum flux (and to a lesser extent 500-mb. heat flux) at 45°N. is generally in phase with the even—odd year difference in sea level zonal wind and 500-mb. temperature.

In order to place these extratropical fluctuations in context with the more familiar tropical fluctuations, at the bottom of figure 10 is plotted the even—odd year difference in temperature in the tropical stratosphere for the January–May period as represented by the average of 30- and 50-mb. temperatures at Balboa (9°N.). There is little longitudinal variation in the quasi-biennial oscillation in the tropical stratosphere so that the Balboa data should be representative of hemispheric conditions. There is an out-of-phase relationship between even—odd year temperature difference in the tropical stratosphere and even—odd year total ozone difference in temperate latitudes. Furthermore, there is a striking similarity between the even—odd difference in sea level zonal wind at 45°N. and the even—odd year difference in stratospheric temperature in the Tropics, with a correlation between the two of 0.96 if the temperature trace is advanced 1 yr. relative to the zonal wind trace. While one hesitates to accept any relation based on only 16 yr. of record, the forecast possibilities here are considerable, particularly if the 1-yr. lag in the relationship is maintained.

7. CONCLUSION

In [1] it was assumed that the 15–20-yr. periodicity in even—odd year differences in extratropical latitudes was due to modulation of the annual cycle by the quasi-biennial cycle, and the authors see no reason to alter their opinion. Thus, an "anomalous" value in, say, March of an even year would again occur in March of an even year after 16 yr. if the quasi-biennial oscillation were of 27.5-mo. period and after 18 yr. if the oscillation were of 27-mo. period. These values are so close to the mean period of the quasi-biennial oscillation deduced from meteorological observations in the tropical stratosphere that the above conclusion seems most likely.

This paper offers no further clues concerning the cause or origin of the quasi-biennial oscillation. However, it does point out the possibility that some long-range forecasting skill may be realized in portions of the temperate latitudes by consideration of the modulation of the annual cycle by the quasi-biennial cycle. As more data are gathered that bear on the interplay of annual and quasi-biennial cycles, the cause of the latter cycle may become apparent.

ACKNOWLEDGMENTS

An analysis of this sort can only be accomplished through the cooperation of many people. The authors gratefully acknowledge receipt of the 40-yr. prewar surface pressure record from W. Kiser and G. Cotten of the Meteorological Statistics Group of the ESSA Research Laboratories, of postwar surface pressure data from P. Clapp and R. Gelhard of the Extended Forecast Division of the Weather Bureau, of 500-mb. geostrophic wind and momentum-flux data from A. Miller of the National Meteorological Center of the Weather Bureau, and of heat flux data from J. Winston and A. Krueger of the National Satellite Center. Dr. M. Mitchell, Jr., of Environmental Data Service proposed pertinent statistical tests, and was kind enough to read a preliminary version of the manuscript.

REFERENCES

1. J. K. Angell and J. Korshover, "Biennial Variation in Springtime Temperature and Total Ozone in Extratropical Latitudes," *Monthly Weather Review*, Vol. 95, No. 11, Nov. 1967, pp. 757–762.
2. J. M. Wallace, "Long Period Wind Fluctuations in the Tropical Stratosphere," *Planetary Circulations Project Report* No. 19, Massachusetts Institute of Technology, Cambridge, Dec. 1966, 167 pp.
3. A. J. Miller, H. M. Woolf, and S. Teweles, "Quasi-Biennial Cycles in Angular Momentum Transports at 500 Mb.," *Journal of the Atmospheric Sciences*, Vol. 24, No. 3, May 1967, pp. 298–304.
4. J. M. Mitchell, Jr., B. Dzerdzeevskii, H. Flohn, W. Hofmeyr, H. Lamb, K. Rao, and C. Wallen, "Climatic Change," *World Meteorological Organization Technical Note* No. 79, Geneva, 1966, 79 pp.
5. D. A. Haines and J. S. Winston, "Monthly Mean Values and Spatial Distribution of Meridional Transport of Sensible Heat," *Monthly Weather Review*, Vol. 91, No. 7, July 1963, pp. 319–328.
6. A. F. Krueger, J. S. Winston, and D. A. Haines, "Computations of Atmospheric Energy and Its Transformation for the Northern Hemisphere for a Recent Five-Year Period," *Monthly Weather Review*, Vol. 93, No. 4, Apr. 1965, pp. 227–238.

[*Received February 21, 1968*]